

washed with water, and was dried *in vacuo* over silica gel. It was purified to constant specific activity by alternate vacuum sublimations (50–60° (0.1 mm.)) and recrystallizations from aqueous ethanol.

**1,3,5-Trimethoxybenzene-2-*t*** (II).—The lithium derivative of 1,3,5-trimethoxybenzene was prepared by the method of Gilman.<sup>27</sup> A twofold excess of tritiated water was added to a suspension of lithium aryl in ether and the mixture was stirred rapidly at room temperature for 10 minutes. The reaction mixture was decomposed by the addition of water, layers were separated, and the ether solution was washed with dilute aqueous sodium hydroxide and with water. The ether solution was then dried over calcium chloride and ether was removed. The residue was sublimed *in vacuo* and the sublimate was purified to constant activity as before.

In a separate experiment, lithium trimethoxybenzene, prepared in the same way, was treated with carbon dioxide; 2,4,6-trimethoxybenzoic acid was isolated in 60% yield, m.p. 144.5–145.0° (reported<sup>28</sup> m.p. 142–144°).

**Fluoroacetic Acid.**—A sample purchased from K. & K. Laboratories was distilled at atmospheric pressure through a 15-plate column. A middle fraction consisting of about one-third of the original charge was collected at 167–168°.

All other materials were reagent grade chemicals. Buffer solutions were prepared either by using appropriate volumes of aqueous acid and sodium hydroxide solutions of known strength, or by diluting accurately weighed amounts of reagent chemicals to known volumes. Aqueous solutions of trimethoxybenzene were prepared by suspending solid trimethoxybenzene in distilled water (a quantity less than that necessary to make a saturated solution was always used; the solubility of trimethoxybenzene in H<sub>2</sub>O at 25° was determined to be 0.43 mg./ml.), heating the mixture past the melting point of trimethoxybenzene (52°), and shaking the suspension mechanically as it cooled to room temperature.

**Kinetic Procedure. Conventional Method.**—Reaction mixtures were prepared either by mixing equal volumes of buffer solution and aqueous trimethoxybenzene-*t* or by mixing 100 volumes of buffer solution with one volume of either aqueous or alcoholic trimethoxybenzene-*t*. The presence of 1% of ethyl alcohol in the reaction mixture had no effect on the rate of exchange. The reaction mixtures were placed in a constant temperature bath (24.62 ± 0.01°) and samples (10, 2 or 1 ml. depending on the concentration and activity of the trimethoxybenzene used) were withdrawn at suitable intervals of time. These samples were quenched in at least a twofold excess of aqueous sodium hydroxide. The

resultant mixtures were shaken mechanically for 1 minute with 15.0-ml. portions of xylene or toluene, the aqueous layers were withdrawn, and the organic solutions were dried with anhydrous CaCl<sub>2</sub>. (A second extraction showed that this procedure removed 99.8% of the trimethoxybenzene-*t* from aqueous solution). Ten-ml. aliquots of the dried solutions were assayed for tritium in a Packard Tri-Carb liquid scintillation counter. The counting data were used directly to calculate first-order rate constants: using machine computation (IBM 704), the data were fitted to the expression  $A = ae^{bt}$  where  $A$  is activity at time  $t$ ,  $a$  is  $A_0 - A_\infty$  and  $b$  is the negative of the first-order rate constant.

**Initial Rate Method.**—Reaction mixtures were prepared by mixing equal volumes of acid solution and a nearly saturated solution of high specific activity trimethoxybenzene in water. These were placed in a constant temperature bath (24.62 ± 0.01°) and 1.00-ml. samples were withdrawn at suitable intervals of time. The samples were quenched in 2.00 ml. of water containing a twofold excess of sodium hydroxide and the resultant mixtures were shaken mechanically with 15 ml. of xylene. The aqueous layers were withdrawn and were washed twice with 15-ml. portions of ethyl ether (control experiments showed that this was sufficient to remove all organically bound tritium). One-ml. aliquots of the washed aqueous solutions were assayed for tritium in a Packard Tri-Carb liquid scintillation counter. These counting data were plotted against time and a straight line was fitted by eye. The slope of this line gave the rate of reaction in c.p.m. per unit time. This was converted to the fraction of reaction ( $x$ ) per unit time from a knowledge of the total activity present in a kinetic sample and the counting efficiency of the aqueous solutions which were assayed. The total activity in a kinetic sample was determined by counting an aliquot of the first xylene extraction of a sample against an aliquot of a xylene solution of benzoic-*t* acid of known activity. The counting efficiency of the aqueous solutions assayed was determined by carrying a sample of water-*t* of known activity through the separation procedure for kinetic samples and then determining its activity under counting conditions similar to those used for kinetic samples. The activities of the standards used in these determinations, benzoic-*t* acid and water-*t*, were each measured several times by a gas-phase counting method which is known to give absolute activities.<sup>29</sup> From the fraction of reaction per unit time, rate constants were calculated using the relationship

$$k_1 = \frac{1}{t} \ln \frac{1}{1-x} \approx \frac{x}{t} \text{ for small } x$$

(27) H. Gilman, C. E. Arntzen and F. J. Webb, *J. Org. Chem.*, **10**, 374 (1954).

(28) J. Herzog and F. Wenzel, *Monatsh.*, **23**, 96 (1902).

(29) D. Christman, *Chemist Analyst* (J. T. Baker Chemical Co.), **46**, No. 1, 5 (1957).

[CONTRIBUTION FROM THE B. F. GOODRICH RESEARCH CENTER AND GOODRICH-GULF CHEMICALS, INC., BRECKSVILLE, OHIO]

## The Rate of Reaction of Maleic Anhydride with 1,3-Dienes as Related to Diene Conformation

BY DAVID CRAIG, J. J. SHIPMAN AND RAY B. FOWLER

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The rate of reaction of fifteen open-chain 1,3-dienes with equivalent concentrations of maleic anhydride has been measured in benzene solution at 25°. Several of the rates were also measured at other temperatures so that heats of activation could be calculated. The heats for the reaction of maleic anhydride with low molecular weight, open-chain dienes are higher than those for 1,3-cyclopentadiene, 2-*t*-butyl-1,3-butadiene or 2-neopentyl-1,3-butadiene. The two highly-branched, open-chain, 2-substituted dienes react very rapidly, the 2-neopentyl derivative reacting about twice as fast as the 2-*t*-butyl and much less rapidly than the cyclic diene. The Raman and infrared spectra of 2-*t*-butyl-1,3-butadiene are consistent with the presence of both *cisoid* and *transoid* conformations. However, spectra studies clearly revealed that the 2-neopentyl derivative is *transoid*. The high rate and low heat of activation for 2-*t*-butyl-1,3-butadiene is understandable on the basis of the presence of more *cisoid* than *transoid* molecules. The *cisoid* form appears to be favored at the expense of the *transoid* the lower the temperature. The 2-neopentyl derivative may react rapidly and with a low heat of activation as a result of the ease of rotation in the complexed state around the diene single bond, which ease appears to be a function of electron availability enhanced by the substituent in the 2-position.

The rate of reaction of 1,3-butadiene with maleic anhydride in benzene solution has been reported by Eisler and Wassermann.<sup>1</sup> They found for

(1) B. Eisler and A. Wassermann, *J. Chem. Soc.*, 1943 (1953); 979 (1953).

equimolecular concentrations a second-order dependence on time for any single mixture. Within experimental error the constants did not change as the starting concentration of the reactants was increased. They reported a heat of activation of

TABLE I  
 RATE DATA FOR THE REACTION OF EQUIMOLECULAR CONCENTRATIONS OF MALEIC ANHYDRIDE AND LOW MOLECULAR

Moles diene per 13.3 ml. Moles per l.	WEIGHT DIENES IN BENZENE			Reaction temp., °C.	Second-order reaction rate constant, $k$ , l./mole/hr.
	0.0283 2.12	0.0200 1.50	0.01415 1.06		
1,3-Diene	Slope of kinetic plot $1/C$ vs. time, hr., $C = \text{fract. unreacted diene}$				
2,3-Dichlorobuta-	0.002			25	$0.002/2.12 = 0.0009$
2-Chlorobuta-	.040			25	$.040/2.12 = .019$
3-Chloro-2-methylbuta-	.260			25	$.260/2.12 = .12$
Buta-		0.290		25	$.290/1.50 = .19$
2-Methylbuta-		0.850		25	$0.850/1.50 = .57$
2-Methylbuta-		1.65		35	$1.65/1.50 = 1.10$
2-Methylbuta- $d_8$		1.05		25	$1.05/1.50 = 0.70$
<i>trans</i> -Penta-		1.38		25	$1.38/1.50 = 0.92$
2-Ethylbuta-		1.85		25	$1.85/1.50 = 1.20$
2-Ethylbuta-			1.20	25	$1.20/1.06 = 1.10$
2-Isopropylbuta-			2.30	25	$2.30/1.06 = 2.2$
2,3-Dimethylbuta-			2.12	25	$2.12/1.06 = 2.0$
2- <i>t</i> -Butylbuta-			5.60	25	$5.60/1.06 = 5.3$
2- <i>t</i> -Butylbuta-			5.25 <sup>b</sup>	25	$5.25/0.902 = 5.8$
2- <i>t</i> -Butylbuta-			3.88	15	$3.88/1.06 = 3.7$
1- <i>t</i> -Butylbuta-	.0200			40	$0.020/2.12 = 0.009$
1- <i>t</i> -Butylbuta-	.0450			50	$0.045/2.12 = 0.021$
2-Neopentylbuta-			10.2	25	$10.2/1.06 = 9.6$
2-Neopentylbuta-			6.6	15	$6.6/1.06 = 6.3$
Cyclohexa-		0.82		25	$0.82/1.50 = 0.55$
Cyclohexa-		1.64		35	$1.64/1.50 = 1.10$
Cyclopenta- <sup>a</sup>		6.00		-40	$6.00/1.50 = 4.0$
Cyclopenta- <sup>a</sup>		1.08		-60	$1.08/1.50 = 0.72$
1-Methoxybuta-			6.34	25	$6.3/1.06 = 6.0$
2-Methoxybuta-		2.90		25	$2.90/1.50 = 1.9$

<sup>a</sup> This run was made at a total volume of 26.6 ml. containing 0.02 mole of each reactant. The solvent was acetone. At  $-40^\circ$  the slope of the kinetic plot = 3.00 and for  $-60^\circ = 0.54$ ; calcd. for 0.02 mole per 13.3 ml. the slopes = 6.00 and 1.08, respectively. <sup>b</sup> Starting concentration for this run was 0.01203 mole per 13.3 ml. or 0.902 mole/l.

11.7 kcal., part of which they ascribe to the energy required for the *transoid-cisoid* change in conformation<sup>1,2</sup> of the diene, the *cisoid* form being the conformation required for the Diels-Alder reaction. Maleic acid and triamylammonium picrate did not influence the rate.

We report here, as complementary to the approach of Eisler and Wassermann, rate data for a variety of dienes and maleic anhydride in equimolecular concentration in benzene but only for a limited number of concentrations and temperatures. The main object of our study is to relate conformation of the diene system and ease of rotation around the diene system to reaction rate and heat of activation. The importance of this problem has increased as a result of the claim, in 1953, by Nikitin and Yakovleva<sup>3</sup> that liquid isoprene, unlike butadiene, is predominantly *cisoid*. At about the same time Szasz and Sheppard<sup>4</sup> reported Raman and infrared spectra to reveal the methyl and chloro derivatives of butadiene to have the *transoid* structure and most workers appear to accept this view. Batuev and others,<sup>5</sup> apparently without knowledge of either the Nikitin or Sheppard papers, have published work strongly supporting the latter. Recent work by Gresser, Rajbenbach and

Szwarc<sup>6</sup> on the methyl affinities of open-chain conjugated dienes also supported the planar *transoid* conformation for these dienes. It is reasonable to expect spectrum and scale model study to reveal the conformation of the low molecular weight dienes and thus to make possible a correlation with rate data at different temperatures.

**Scale Models and Conformation.**—Backer<sup>7</sup> was among the first to consider diene conformation and reactivity in the Diels-Alder reaction. He found 2,3-di-*t*-butyl-1,3-butadiene to be totally unreactive with maleic anhydride. His studies with scale models showed that this diene cannot exist in the *cisoid* conformation, and even *transoid* conformation is highly hindered. The most probable form is non-planar *transoid*, i.e., with the double bonds not in the same plane. In agreement with this view we find the diene to display an absorption peak in the ultraviolet in iso-octane at 213 m $\mu$ , a wave length too short for the double bonds to be fully conjugated and coplanar. Although the behavior of the 2,3-di-*t*-butyl derivative is important as a limiting case, it reveals little as to the expected behavior of 1,3-dienes having small volume substituent groups. Almost every 1,3-diene has some structural feature of interest in the diene synthesis.

Scale models of the chloro and methylsubstituted butadienes listed in Table I (*cis*-1,3-pentadiene is

(2) B. Eisler and A. Wassermann, *Faraday Soc. Disc.*, **10**, 235 (1951).

(3) V. N. Nikitin and T. V. Yakovleva, *Zhur. Fiz. Khim.*, **28**, 692 (1954); **28**, 697 (1954).

(4) G. J. Szasz and N. Sheppard, *Trans. Faraday Soc.*, **49**, 358 (1953).

(5) M. I. Batuev, A. S. Onishchenko, A. D. Matreeva and N. I. Aronova, *Doklady Akad. Nauk USSR*, **132**, 581 (1960).

(6) J. Gresser, A. Rajbenbach and M. Szwarc, *J. Am. Chem. Soc.*, **82**, 5820 (1960).

(7) H. J. Backer, *Rec. trav. chim.*, **58**, 643 (1939).

not included here as it will be discussed separately) show no hindrance, or very little, to rotation around the diene single bond and planar *transoid* and *cisoid* conformations are clearly possible. As we go up the series of alkyl derivatives a difference between 2- and *trans*-4-substitution is apparent. That is, at the 4-position of the diene there is adequate space for even large alkyl groups if the 3,4-double bond configuration is *trans*<sup>8</sup>; for the adducts of these dienes, however, the alkyl groups, even methyl, in the 3-position of the all-*cis* tetrahydrophthalic anhydride are *hindered* and the effect increases with the size of the alkyl. On the contrary, models of the adducts (4-substituted tetrahydrophthalic anhydrides) of the 2-alkyl dienes are all *unhindered* as is the *cisoid* conformation of the dienes themselves, but the *transoid* conformation becomes more hindered as the size of the 2-alkyl is increased in the order  $\text{CH}_3$ ,  $\text{C}_2\text{H}_5$ , *iso*- $\text{C}_3\text{H}_7$ , neo- $\text{C}_4\text{H}_9$  and *t*- $\text{C}_4\text{H}_9$ . Thus, 2-*t*-butyl-1,3-butadiene would not be expected to exist in a fully planar *transoid* conformation, but the planar *cisoid* conformation is unhindered. The diene system on one side can be exposed as completely as in 1,3-butadiene, isoprene or 1,3-cyclopentadiene. When a hydrogen of the methyl group in the isoprene scale model is replaced by a *t*-butyl group, the resulting 2-neopentyl-1,3-butadiene is found to be almost unhindered in the planar *cisoid* form and somewhat hindered in the *transoid* form. However, the *transoid* form is notably not forbidden and is considerably less hindered than *transoid*-2-*t*-butyl-1,3-butadiene. The planar *cisoid* conformation, the one required for reaction with maleic anhydride, has novel structural features. These include (1) coplanarity (or, at least the possibility of coplanarity) of the 1,3-diene system completely exposed on one side (with no *centroid* substituents), and (2) effective shielding by the *t*-butyl group on the other side. It should be mentioned here that the rotations of the unsubstituted vinyl group and the *t*-butyl group are facilitated by the methyl groups and one hydrogen of the vinyl group intermeshing and acting as teeth in intermeshing gears. It is believed that these features contribute to an interesting reaction rate as set forth in the following section.

Substitution of *cis*-4-methyl in butadiene gives *cis*-1,3-pentadiene, the scale model of which is hindered in the *cisoid* conformation. In spite of this the *trans,cis,cis* adduct of this diene actually forms stereospecifically but only under forcing conditions.<sup>9</sup> Since the model of the adduct shows no hindrance, it is believed that slowness in rate (the rate is substantially nil at room temperature) must be due to hindrance to the formation of a planar *cisoid* conformation of the diene needed to facilitate the transition state of the reaction.

Braude<sup>10</sup> has stated that 1,3-cyclohexadiene, which is known to be of low activity, has a planar

(8) D. Craig, *J. Am. Chem. Soc.*, **65**, 1006 (1943).

(9) D. Craig, *ibid.*, **72**, 1678 (1950). The yield of stereospecific adduct at 100° was only 4% largely because of polymerization. More recently, equimolar amounts of the reactants in the presence of picric acid and di-*n*-butylamine have given 52% of this adduct (the *trans*-methyl isomer) and none of the all-*cis* adduct. The picric acid-amine combination is an effective inhibitor of polymerization.

(10) E. A. Braude, *Chemistry & Industry*, 1557 (1954).

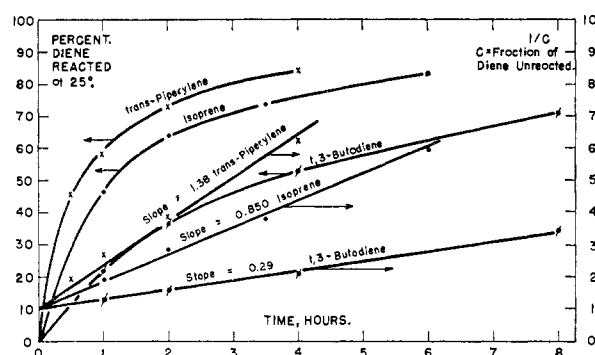


Fig. 1.—The reaction of butadiene, isoprene and piperylene with maleic anhydride in benzene.

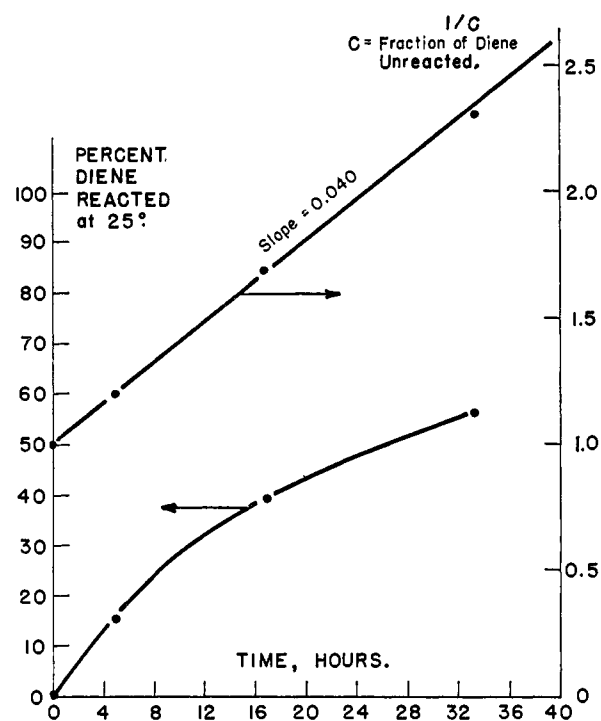


Fig. 2.—The reaction of chloroprene with maleic anhydride in benzene.

diene system structure. The scale model of its probable conformation reveals one *centroid* hydrogen atom on each side of a plane running through the diene system. This exerts a shielding effect on both sides of the molecule. A planar structure with the four methylenic hydrogen atoms equidistant from the diene system plane is definitely strained and so would not need consideration in the Diels-Alder reaction.

**Substitution and Reaction Rate.**—Table I summarizes our data in the form of second-order reaction rate constants. These were computed in a standard way by dividing the slopes of the kinetic plots by the initial diene concentration. Figures 1 and 2 show some of the rate curves and kinetic plots.

It is apparent from Eisler and Wassermann's work<sup>1,2</sup> and from our data that the low molecular weight dienes react with maleic anhydride according to the second-order rate law. Our constant for

1,3-butadiene (for 1.5 moles/l.) is 0.19 l./mole/hr. in comparison to Eisler and Wassermann's value of 0.138. Since their method of following the rate depended on measuring the change in vapor pressure of the reacting mixture and our method depended on measuring the amount of diene consumed in various time intervals, the data are believed to be in satisfactory agreement.

2-Chloro substitution is strongly retarding as may be seen from the rates of reaction of the three 2-chlorobutadienes as compared to butadiene itself. This effect is greater than the activating effect of 2-methyl substitution. This is noticeable in 2-chloro-3-methyl-1,3-butadiene whose rate is nearer that for chloroprene than it is to the isoprene rate and is appreciably lower than the butadiene rate. Carothers and co-workers,<sup>11</sup> according to Norton, found 1-chloro-1,3-butadiene not to react with maleic anhydride. We find the *trans* isomer (see Tables I and III) of this diene to react very slowly and the *cis* isomer not at all. Contrary to their work,<sup>11</sup> we find 2,3-dichloro-1,3-butadiene to react to form an adduct having the composition of 4,5-dichloro-4-cyclohexene-1,2-dicarboxylic anhydride.

The activating effect of 2- as well as *trans*-1-methyl substitution, evident from the data of Table I, may be explained on the basis of electron release to the 1,3-diene system. Except for *cis*-4-methyl substitution,<sup>8,9</sup> which substantially stops reaction at 25° as explained by models in the preceding section, an explanation similar to the one for alkyl substituted dienes may be advanced for high reaction rates of the methoxy butadienes. An expected greater rate for perdeuterio-isoprene over that of protio-isoprene follows from the work of Elliot and Mann<sup>12</sup> who found that the N-deuterio- as well as the C-deuterio-anilines react faster (second-order kinetics being observed) with benzoyl chloride than do the corresponding protio compounds. They ascribe greater electron-releasing power to deuterium relative to protium. However, the constant 0.70 for C<sub>6</sub>D<sub>6</sub> as compared to 0.57 for C<sub>6</sub>H<sub>6</sub> in Table I does not establish an isotope effect in the diene synthesis. The retarding effect of chloro substitution may be explained as being due to the electron withdrawal effect of the chlorine atom.

The data in Table I show that the rate increases rather rapidly with the size of the 2-alkyl substituent in line with the hindrance revealed for scale models as discussed in the previous section. The Diels-Alder reactivity of the 2-*t*-butyl derivative is noteworthy since it is an open-chain 1,3-diene strongly hindered in the *transoid* conformation, not hindered in the *cisoid* form, but which forms an unhindered adduct. It was found to be very reactive with maleic anhydride having a rate constant  $K_{25^\circ}$  of 5.3. On the other hand, 1-*t*-butyl-1,3-butadiene, presumably the *trans* isomer, has been found to react slowly with a constant of only 0.0094 at 40°. As related in the preceding section, this low rate may be ascribed to the difficult

steric requirement of *t*-butyl in the 3-position of the all-*cis* adduct or, perhaps as realistically, to the steric requirements of the transition state preceding adduct formation.

1,3-Cyclohexadiene is in a sense a *cis,cis*-1,4-disubstituted butadiene in which the diene single bond has the necessary *cis* configuration. Its rate constant,  $K_{25^\circ} = 0.55$ , is however relatively low. Thus, it is only about as active as isoprene and much less active than 1,3-cyclopentadiene. A plausible reason for its low activity is the shielding provided by the two *centroid* hydrogen atoms mentioned in a previous section.

#### Temperature and Reaction Rate.—Table II

TABLE II  
ACTIVATION ENERGIES AND FREQUENCY FACTORS FOR THE REACTION OF VARIOUS DIENES WITH MALEIC ANHYDRIDE

Diene	Activa- tion energy, <sup>a</sup> kcal.	Log of fre- quency fac- tor, <sup>b</sup> A	Temp. range, °C.	$K_{25^\circ}$ , l./mole/ hr.
1- <i>t</i> -Butyl-1,3-butadiene	16.4	5.2	40-50	0.0025 <sup>c</sup>
1,3-Cyclohexadiene	12.7	5.5	25-35	.55
Isoprene	12.2	5.1	25-35	.57
1,3-Butadiene <sup>d</sup>	11.7	4.2	14.4-55	.138
1,3-Cyclopentadiene	8.5	5.0	-60 to -40	220 <sup>e</sup>
2-Neopentyl-1,3-butadiene	7.6	2.3	15-25	9.6
2- <i>t</i> -Butyl-1,3-butadiene	6.3	1.8	15-25	5.3

<sup>a</sup>  $E$ , computed from  $\log \frac{K_2}{K_1} = \frac{E}{2.30R} \left( \frac{T_2 - T_1}{T_2 T_1} \right)$  where  $K_2$  and  $K_1$  are the second-order rate constants at absolute temperatures  $T_2$  and  $T_1$ , respectively,  $E$  is the activation energy, and  $R$  is the gas constant. <sup>b</sup> Computed from the equation  $2.3 \log (K_{25^\circ}/3600) = 2.3 \log A - E/RT$ . The units of  $A$  are l./mole/sec. <sup>c</sup> Computed from  $K_{40^\circ} = 0.0094$  l./mole/hr. and  $E = 16.4$  kcal. <sup>d</sup> Data of Eisler and Wassermann.<sup>1</sup> <sup>e</sup> Computed from  $K_{40^\circ} = 4.0$  l./mole/hr. and  $E = 8500$  cal./mole.

summarizes the effect of temperature on reaction rate for open-chain and cyclic dienes and maleic anhydride. The activation energy data are in line with Eisler and Wassermann's deduction that the energy of rotation around the 1,3-diene single bond of those dienes normally *transoid* should contribute significantly to the activation energy. Such a diene is 1,3-butadiene itself. The two bulky 2-substituted dienes have energies of activation 4 or more kcal. smaller than the low molecular weight dienes whose scale models show no hindrance to rotation around the diene single bond. The fast rate and low heat of activation for the 2-neopentyl derivative are understandable on the basis that it also has little hindrance to rotation around the diene single bond. Since the rate of reaction is first order in both diene and dienophile, this ease of rotation must be effective in a complexed state involving both reactants. The ease of rotation in the complexed diene system may be enhanced by the electron release activity of the neopentyl group to such an extent that the rate of reaction is faster than for 2-*t*-butyl-1,3-butadiene which cannot exist readily in the *transoid* conformation.

1,3-Cyclopentadiene reacted at 25° much too fast for accurate study by our technique even at a concentration of 0.2 mole per liter. However, by using acetone as the solvent instead of benzene liquid systems at -40° to -60° are obtained and rates can be measured. Understandably, it is

(11) J. A. Norton, *Chem. Revs.*, **31**, 379 (1942), summary of Diels-Alder reactions, including those with chlorodienes; G. H. Berchet and W. H. Carothers, *J. Am. Chem. Soc.*, **55**, 2007 (1933).

(12) J. J. Elliot and S. F. Mann, *Chemistry & Industry*, 488 (1959).

TABLE III  
 INFRARED AND RAMAN C=C STRETCHING FREQUENCIES<sup>a</sup> FOR SOME 2-ALKYL-1,3-BUTADIENES IN LIQUID PHASE AT 26°

Substituent	Infrared			Raman <sup>b</sup>		
	Sym., cm. <sup>-1</sup>	Antisym., cm. <sup>-1</sup>	$I_s/I_a$	Sym., cm. <sup>-1</sup>	Antisym., cm. <sup>-1</sup>	Relative $I_s$
Methyl	1642(w)	1595(s)	0.04	1645(s)	1595(vw)(sh)	19
Ethyl	1633(w)	1590(s)	.07	1645(s)	1590(vw)(sh)	16
Isopropyl	1632(w)	1590(s)	.12	1640(s)	1580(vw)(sh)	15
<i>t</i> -Butyl <i>cisoid</i>	1611(s)	1645(w)(sh)	<sup>c</sup>	1610(s)		4
<i>t</i> -Butyl <i>transoid</i>	1625(w)(sh)	1595(w)(sh)	<sup>c</sup>	1650(vw)(sh)		
Neopentyl	1642(w)	1596(s)	0.20			

<sup>a</sup> s = strong, w = weak, vw = very weak, sh = shoulder;  $I_s$  = intensity symmetrical,  $I_a$  = intensity antisymmetrical.  
<sup>b</sup> We are happy to acknowledge that these data were supplied by the Applied Physics Corp., Monrovia, Calif. <sup>c</sup> See text.

necessary here to correct for the diene reacting during the evaporation at about  $-40^\circ$  of diene and solvent. The activation energy, 8.5 kcal., for the reaction of this diene is low as would be expected from the fact that no change in conformation is required to form a planar transition state as pointed out by Eisler and Wassermann.<sup>2</sup> They also found a low activation energy for the reaction of cyclopentadiene with quinone. The relatively slow rate and high activation energy for 1,3-cyclohexadiene, which according to Braude<sup>10</sup> has a planar *cis* diene single bond, evidently must be due in part to features other than diene planarity. A possible effect is shielding of the diene system by *centroid* hydrogen atoms. Other properties no doubt include unfavorable bond angles and lengths in the diene as well as steric requirements of the adduct in respect to transition state formation and conversion to product. And, of course, the slow rate and high activation energy for 1-*t*-butyl-1,3-butadiene are due mostly to such properties as well as to the energy required for change in conformation. Though not of paramount importance to the argument here, it is not established whether reaction of this diene is stereospecific. Thus Alder, Heimbach and Kuhle<sup>13</sup> isolated only a 65% yield of the adduct, m.p.  $138^\circ$ , presumably having the all-*cis*-configuration. A second adduct, possibly the *trans,cis,cis* isomer, definitely is present.

Andrews and Keefer<sup>14</sup> found for the slow reaction (relative rate = 1) in chloroform of maleic anhydride with anthracene an activation energy of 13.1 kcal., but for the rapid reaction of 9,10-dimethylantracene with maleic anhydride (relative rate = 2100) a value of only 8.0 kcal. The logs of the pre-exponential factors were 5.2 and 4.7, respectively, so that the difference in rate according to the equation  $k = Ae^{-E/RT}$  must be due mostly to the difference in activation energy. Steric effects of substituents in the reactants appeared unimportant in determining the relative rates in their study. In acetone they found an activation energy for the dimethylantracene reactions of 11.3 kcal. and a slower rate. Complexing, which was important in chloroform (the reciprocal of the rate constant increasing sharply with increase in concentration of reactants), was not noticeable in acetone where the rate constant was independent of concentration. This behavior accords with the findings of Eisler and Wassermann<sup>1</sup> that the butadiene-maleic anhydride reaction rate constant

in benzene does not change with increase in concentration of reactants. The findings of Andrews and Keefer that the reaction of anthracene and dimethylantracene with maleic anhydride can have a high heat of activation is similar to the finding reported here for 1,3-cyclohexadiene. Such behavior does not negate the proposal of Eisler and Wassermann that the change in conformation is responsible for a large part of the energy of activation for the Diels-Alder reaction of *transoid* dienes.

**Infrared-Raman Spectra Method for Determining the Conformation of 2-Substituted-1,3-dienes.**—Szasz and Sheppard<sup>4</sup> reported that the symmetrical in-phase C=C stretching vibrations of isoprene and 2-chloro-1,3-butadiene produce very strong Raman bands while the antisymmetrical out-of-phase C=C stretching modes give rise to very strong infrared absorption bands and that the mutual exclusion rule<sup>15</sup> was almost obeyed for the particular bands. On this basis they assigned the planar *transoid* configuration to these molecules. This implies that substitution of a methyl group or chlorine atom in the 2-position of 1,3-butadiene only slightly disrupts the electrical symmetry of the four-carbon chain in the direction parallel to the two double bonds. As the size and bulk of the alkyl in the 2-position of open-chain 1,3-dienes increase, we should observe progressively greater deviations from the mutual exclusion rule due to reduction of symmetry with respect to the two double bonds. The infrared and Raman data for some 2-alkyl-1,3-butadienes are shown in Table III. All members of the series of compounds listed in Table III except 2-*t*-butyl-1,3-butadiene have very similar infrared and Raman spectra in the C=C stretching region. Their infrared spectra show two distinct C=C stretching bands, the low frequency band being much more intense than the other. In the Raman spectra single prominent C=C stretching bands are observed with extremely weak shoulders on the low-frequency wings of the bands. Since the frequency of the strong infrared band does not agree with the frequency of the strong Raman band we must be dealing with a system which is capable of two C=C stretching vibrations, one of which is antisymmetrical giving rise to a strong infrared band and one which is symmetrical producing a strong Raman band. The planar *transoid* configuration is the only possible structure for these molecules which can satisfy this condition. The mutual exclusion rule is not being strictly obeyed in this series of molecules as revealed by the

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(14) L. J. Andrews and R. M. Keefer, *J. Am. Chem. Soc.*, **77**, 6284 (1955).

(15) G. Herzberg, "Infrared and Raman Spectra," D. Van Nostrand Co., Inc., New York, N. Y., 1945, p. 256.

presence of two infrared C=C stretching bands. As shown in Table III, the intensity of the symmetrical C=C band relative to the intensity of the antisymmetrical C=C band increases as the size of the alkyl group becomes larger and the relative intensity of the Raman C=C stretching bands diminishes. It is concluded that these molecules are all predominantly *transoid* in configuration, but that the actual structures deviate from the planar *transoid* forms by small amounts which depend on the size of the alkyl group.

The data in Table III indicate that 2-*t*-butyl-1,3-butadiene is considerably different from the other dienes in that the frequency of the strong infrared C=C stretching band agrees quite well with the frequency of the Raman C=C stretching band. This means that no center of symmetry exists with respect to the two double bonds. The C=C infrared stretching bands are not well resolved for this compound; a band envelope is obtained with the maximum absorption at 1611 cm.<sup>-1</sup> and shoulders as indicated in the table. The intensity at 1611 cm.<sup>-1</sup> is much less than those obtained for the antisymmetrical C=C bands for the other compounds. On cooling to near Dry-Ice temperature the 1611 cm.<sup>-1</sup> band increased in intensity, the shoulders at 1595 and 1625 cm.<sup>-1</sup> became less intense, and no change was noted between the room temperature and near Dry-Ice temperature spectra for 2-neopentyl-1,3-butadiene. These results show that more than one form of 2-*t*-butyl-1,3-butadiene is present in the liquid in the temperature range of the experiments. From the coincidence of the frequencies of the strongest infrared C=C band and strongest Raman C=C band it must be concluded that the conformation which predominates has very little symmetry with respect to the double bonds. This is supported by weakness of the Raman C=C band at 1610 cm.<sup>-1</sup> with respect to those of the other compounds in the 1640 to 1645 cm.<sup>-1</sup> region. The most likely structure for 2-*t*-butyl-1,3-butadiene is a mixture of planar and non-planar *cisoid* configurations.

The findings reported here concerning the conformation of isoprene and other substituted 1,3-dienes agree with those of Szasz and Sheppard<sup>4</sup> and oppose those of Nikitin and Yakovleva.<sup>5</sup>

### Experimental

The maleic anhydride, m.p. 53–54°, was a commercial grade which contained enough maleic acid to give a turbid solution in benzene. The benzene was dried azeotropically. Butadiene, isoprene, 2-ethyl-1,3-butadiene, *trans*-1,3-pentadiene, 2,3-dimethyl-1,3-butadiene and chloroprene were found to be of better than 99.0% purity by vapor phase chromatography. 2,3-Dichlorobutadiene, 2-chloro-3-methyl-1,3-butadiene and 2-neopentyl-1,3-butadiene also are believed to have been of this purity. 2,3-Dichlorobutadiene was recrystallized from pentane to a constant melting point of about -40°. The 3-chloro-2-methyl-1,3-butadiene was a distilled commercial sample. 2-Isopropyl-1,3-butadiene and 2-*t*-butyl-1,3-butadiene were prepared by Normant's procedure<sup>16</sup> from the reaction of vinylmagnesium chloride with methyl isopropyl ketone and methyl *t*-butyl ketone, respectively. The 1-*t*-butyl derivative was prepared from *t*-butylmagnesium chloride and crotonaldehyde according to the procedure of Alder, Heimbach and Kuhle.<sup>18</sup> These three dienes prepared by the Grignard reaction were probably 97–99% pure and had properties nearly the same as those

previously reported.<sup>17</sup> 2-Methoxy-1,3-butadiene was prepared by the method of Petrov.<sup>18</sup> 1-Methoxy-1,3-butadiene (Carbide & Carbon Chemicals Corp.) and 1,3-cyclohexadiene (Farchan Chemical Co.) were purchased. Physical properties for some of the dienes are given in Table IV.

TABLE IV  
PROPERTIES OF LESS COMMON DIENES

1,3-Butadiene derivative	$n_D^{20}$	B.p., °C. at 740 mm.	M.p. of MA adduct, °C.	Diene content, % <sup>c</sup>
2-Isopropyl	1.4340	85.6	87–88	97
2- <i>t</i> -Butyl	1.4285	100	...	98
<i>trans</i> -1- <i>t</i> -Butyl	1.4433	105	137	99
2-Neopentyl	1.4431	125	116	100
<i>trans</i> -1-Methoxy	1.4653	88.5	99	99
2-Methoxy	1.4448	73.2	...	..
<i>trans</i> -1-Chloro <sup>a</sup>	1.4722	66.5	143	99
2,3-Dichloro		43 <sup>b</sup>	117	99
1,3-Cyclohexadiene	1.4745	79.0	145–146	99
2-Methyl- <i>d</i> <sub>8</sub> <sup>d</sup>	1.4189	31.8	62.2	99

<sup>a</sup> To be reported on in a forthcoming paper. A. S. Onishchenko and N. I. Aranova, *Doklady Akad. Nauk, SSSR*, **132**, 138 (1960), reported the maleic anhydride adduct to melt at 130–131°. <sup>b</sup> At 85 mm. <sup>c</sup> Determined as in the rate experiments except that the reaction mixtures were finally heated at 100° for 30 to 60 minutes before working up. An excess of maleic anhydride was used in the determination. <sup>d</sup> D. Craig, F. A. Regenass and R. B. Fowler, *J. Org. Chem.*, **24**, 244 (1959). According to mass spectrum analysis the isotopic purity corresponded approximately to 20 mole % C<sub>5</sub>H<sub>7</sub>D and 80 mole % C<sub>5</sub>D<sub>8</sub>.

2-Neopentyl-1,3-butadiene sulfone was prepared as for the sulfone of 1,3-pentadiene.<sup>8</sup> Crystallized from methanol the compound melted at 91–92°.

*Anal.* Calcd. for C<sub>8</sub>H<sub>16</sub>SO<sub>2</sub>: C, 57.40; H, 8.57. Found: C, 57.37; H, 8.63.

The sulfone decomposed at 50 mm. and 130° at about the same rate as isoprene sulfone at 1 atmosphere and 130°. The recovered neopentyl butadiene had properties (Table IV) in agreement with those reported by Blomquist and Westfahl.<sup>19</sup>

4,5-Dichloro-4-cyclohexene-1,2-dicarboxylic Anhydride.—2,3-Dichloro-1,3-butadiene was recrystallized twice from pentane at about -70°. It then melted at about -40°, b.p. 44° at 87 mm. One-tenth mole (12.3 g.) of the diene, 0.1 mole (9.8 g.) of maleic anhydride, 0.1 g. of phenyl-2-naphthylamine and 0.1 g. of *t*-butylcatechol were mixed and allowed to stand for 2 days at 40–45°. Evaporation at 0.5 mm. and up to a final temperature of 75° at the end of 2 hours gave 2.3 g. of condensate and 19.9 g. (90%) of distillate consisting of large transparent crystals. Recrystallization from benzene gave 15.0 g. (70%) of colorless crystals melting at 116–117°.

*Anal.* Calcd. for C<sub>8</sub>H<sub>8</sub>Cl<sub>2</sub>O<sub>3</sub>: C, 43.46; H, 2.74; Cl, 32.08. Found: C, 43.30; H, 2.95; Cl, 32.15.

The rate experiments were carried out in narrow-mouth screw-cap bottles, either 1 or 2-oz. size, which were fitted with inserts about 5 mm. thick cut from size O rubber stoppers. The volume of reaction mixture usually was 13.3 ml. The bottle and insert were tared separately and the maleic anhydride and benzene weighed in. In many experiments an antioxidant was added. The insert was quickly seated and the bottle swirled to dissolve the maleic anhydride after which the bottle was cooled to about 5°. The required diene was injected with a syringe, the bottle weighed, capped, shaken and placed in the constant temperature bath. The reaction was stopped at the desired time by cooling, first briefly in ice-water and then in Dry Ice. In the case of higher boiling dienes such as the *t*-butyl derivatives, the stopping step was facilitated by injecting 10 ml. of isoöctane just

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(19) A. T. Blomquist and J. C. Westfahl, *J. Am. Chem. Soc.*, **74**, 4073 (1952).

(16) H. Normant, *Angew. Chem.*, **67**, 760 (1955).

prior to cooling. Unreacted diene and solvent were then evaporated through tared connections to a series of two tared Dry Ice cooled traps at a pressure of 0.5 to 20 mm., depending on the diene, the bottle being warmed to 25–40°. This was continued until the loss in weight of the bottle equalled the gain in weight of the connections to the traps. The condensate in the first trap was evaporated at reduced pressure to give a small residue. The reacted diene was considered to be this residue plus the condensate in the connections plus the weight of reaction mixture in the bottle minus

the starting maleic anhydride minus the antioxidant (if any) minus the increase in weight of the insert. Corrections for diene reacted during the evaporation were necessary only in the cases of 2-neopentylbutadiene and cyclopentadiene; they amounted to 1 to 6% for the neopentyl derivative and 10 to 15% for cyclopentadiene.

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## Intramolecular Assistance of Decarboxylative Acylation

BY PHILIP A. CRUICKSHANK AND JOHN C. SHEEHAN

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Simple  $\gamma$ - and  $\delta$ -dialkylamino acids unsubstituted at the  $\alpha$ -position and having primary alkyl substituents on nitrogen have been found to react with carboxylic acid anhydrides to afford  $\gamma$ - and  $\delta$ -dialkylamino ketones. When the substituents on nitrogen are secondary alkyl or benzyl the reaction takes a different course, affording lactams and alkyl esters.

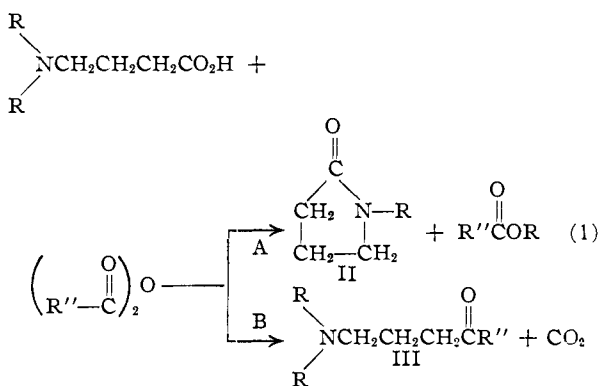
Intramolecular interactions between functional groups in a molecule frequently will lead to reactions which take place with difficulty, if at all, when the interactions are of an intermolecular nature. We wish to report some new reactions of  $\gamma$ - and  $\delta$ -dialkylamino acids with carboxylic acid anhydrides due presumably to intramolecular interactions of the carboxyl and tertiary amine groups. The reactions observed are a decarboxylative acylation to afford  $\gamma$ - or  $\delta$ -dialkylamino ketones and/or carbon-nitrogen cleavage to afford lactams and alkyl esters. These reactions are not normally encountered in mixtures of simple carboxylic acids, carboxylic acid anhydrides and tertiary amines.

Intramolecular reactions of  $\gamma$ - and  $\delta$ -dialkylamino acids have been observed previously.<sup>1–5</sup> Acid chlorides of these compounds when heated afford pyrrolidones and piperidones, respectively, as well as one equivalent of alkyl chloride.<sup>1,2</sup> This reaction appears to be general when run under the proper conditions, *e.g.*, use of phosphorus trichloride to form the acid chloride followed by heating the solid product to 160° or higher.<sup>2</sup> Thionyl chloride could be used if the dialkylamino acid was free of  $\alpha$ -hydrogen; if not, sulfurous products predominated. Pyrolysis of  $\gamma$ -dialkylamino acids<sup>3,4</sup> and of their corresponding "betaines"<sup>5</sup> was shown to give  $\gamma$ -lactones and the secondary or tertiary amines.

During an investigation of the chemistry of 18-substituted solanidane alkaloids (isorubijervine derivatives) it was observed that solanidane-18-oic acids reacted with acetic anhydride to afford neutral products.<sup>6</sup> These neutral compounds were shown to be "acetoxy-lactams" formed by attack of the carboxyl carbonyl on the nitrogen atom

with concomitant cleavage of the C(16)-N bond and introduction of an acetoxy group at C(16). In order to determine whether this lactam-forming reaction was general, several simple  $\gamma$ -dialkylaminobutyric acids and a  $\delta$ -dialkylaminovaleric acid were investigated in respect to reactions with carboxylic acid anhydrides.

The reaction was first studied with simple  $\gamma$ -dialkylamino derivatives of butyric acid (I). The nature of the principal products of the reaction between these acids and the anhydrides was found to be dependent upon the type of alkyl group substituted on the nitrogen. With secondary alkyl substituents, *e.g.*,  $\gamma$ -(N,N-dicyclohexylamino)-butyric acid, or benzyl substituents,  $\gamma$ -(N,N-dibenzylamino)-butyric acid, the expected pyrrolidone II and secondary alkyl or benzyl ester were formed (eq. I, path A). However, when both



nitrogen substituents were primary alkyl, *e.g.*,  $\gamma$ -(1-piperidino)-butyric acid, an unexpected reaction resulted, formation of a  $\gamma$ -dialkylamino ketone (III; eq. I, path B). This ketone was formed by incorporation of an acyl group from the anhydride and loss of carbon dioxide. In the one instance in which a mixed dialkylamino group was investigated,  $\gamma$ -(N-methyl-N-benzylamino)-butyric acid, both lactam and ketone were formed with the former predominating. Ketone also was formed when the nitrogen was substituted with a secondary alkyl group in the acid chain,  $\gamma$ -(4-morpholino)-valeric

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